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भारतीय मानक

प्रोत्कर्ष निरोधक

भाग 5 चयन एवं अनुप्रयोग की अनुशंसाएँ

Indian Standard

SURGE ARRESTERS

PART 5 SELECTION AND APPLICATION RECOMMENDATIONS

ICS 29.120.50;29.240.10

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BUREAU OF INDIAN STANDARDS
MANAK BHAVAN, 9 BAHADUR SHAH ZAFAR MARG
NEW DELHI 110002

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Surge Arrestors Sectional Committee, ET 30

NATIONAL FOREWORD

This Indian Standard (Part 5) which is identical with IEC 60099-5 (1996) 'Surge arresters — Part 5 : Selection and application recommendations' issued by the International Electrotechnical Commission (IEC) was adopted by the Bureau of Indian Standards on the recommendation of the Surge Arrestors Sectional Committee and approval of the Electrotechnical Division Council.

The text of IEC Standards has been approved as suitable for publication as Indian Standard without deviation. Certain conventions are, however, not identical to those used in Indian Standards. Attention is particularly drawn to the following:

a) Wherever the words 'International Standards' appear referring to this standard, they should be read as 'Indian Standard'; and

b) Comma (,) has been used as a decimal marker while in Indian Standards, the current practice is to use a point (.) as a decimal marker.

With the publication of this standard, IS 4004 : 1985 'Application guide for non-linear resister type surge arresters for alternating current systems (*first revision*)' shall be treated as withdrawn.

CROSS REFERENCES

In this adopted Indian Standard, references appear to certain International Standards for which Indian Standards also exist. The corresponding Indian Standards, which are to be substituted in their respective places are listed below along with their degree of equivalence:

International Standard	*Corresponding Indian Standard*	*Degree of Equivalence*
60071-1 : 1993 Insulation co-ordination — Part 1 : Definitions, principles and rules	IS 2165 (Part 1) : 1977 Insulation coordination : Part 1 Phase to earth insulation coordination principles and rules (*second revision*)	Equivalent
	IS 2165 (Part 2) : 1983 Insulation coordination: Part 2 Phase to phase insulation coordination principles and rules	do
60071-2 : 1996 Insulation coordination — Part 2 : Application guide	IS 3716 : 1978 Application guide for insulation coordination (*first revision*)	do
60099-1 : 1991 Surge arresters — Part 1 : Non-linear resistor type gapped arresters for ac systems	IS 15086 (Part 1) : 2001/IEC 60091-1 : 1991 Surge arresters : Part 1 Non-linear resistor type gapped arresters for a.c. systems	Identical
60099-3 : 1990 Surge arresters — Part 3 : Artificial pollution testing of surge arresters	Nil	
60099-4 : 1991 Surge arresters — Part 4 : Metal oxide surge arresters without gaps for ac systems	IS 3070 (Part 3) : 1993 Lightning arresters for alternating current systems: Part 3 Metal oxide surge-arresters without gaps for ac systems	Equivalent

(*Continued on third cover*)

Indian Standard
SURGE ARRESTERS
PART 5 SELECTION AND APPLICATION RECOMMENDATIONS

1.1 Scope

This part of IEC 99 provides recommendations for the selection and application of surge arresters to be used in three-phase systems with nominal voltages above 1 kV. It applies to non-linear resistor type gapped surge arresters as defined in IEC 99-1 and to gapless metal-oxide surge arresters as defined in IEC 99-4.

1.2 Normative references

The following normative documents contain provisions which, through reference in this text, constitute provisions of this part of IEC 99. At the time of publication, the editions indicated were valid. All normative documents are subject to revision, and parties to agreements based on this part of IEC 99 are encouraged to investigate the possibility of applying the most recent editions of the normative documents indicated below. Members of IEC and ISO maintain registers of currently valid International Standards.

IEC 71-1: 1993, *Insulation co-ordination – Part 1: Definitions, principles and rules*

IEC 71-2: 1976, *Insulation co-ordination – Part 2: Application guide*

NOTE – The third edition of this standard is presently under revision.

IEC 99-1: 1991, *Surge arresters – Part 1: Non-linear resistor type gapped surge arresters for a.c. systems*

IEC 99-3: 1990, *Surge arresters – Part 3: Artificial pollution testing of surge arresters*

NOTE – This Technical Report applies to gapped surge arresters according to IEC 99-1.

IEC 99-4: 1991, *Surge arresters – Part 4: Metal-oxide surge arresters without gaps for a.c. systems*

IEC 507: 1991, *Artificial pollution tests on high-voltage insulators to be used on a.c. systems*

IEC 815: 1986, *Guide for the selection of insulators in respect of polluted conditions*

1.3 General principles for the application of surge arresters

IEC 71-1 specifies withstand voltages for two ranges of highest voltages for equipment:

- range I: above 1 kV to 245 kV included
- range II: above 245 kV

For range I systems containing overhead lines, the main risk to equipment arises from induced and direct lightning strokes to the connected overhead lines. In cable systems not connected to overhead lines, overvoltages due to faults or switching operations are most likely to occur. In rare cases, however, lightning induced overvoltages may also be generated. In systems of range II, in addition to range I factors, switching overvoltages become important, increasing with higher system voltages. Overvoltages may cause flashovers and serious damage to the equipment and thereby jeopardize the supply of power to users. It is essential to prevent this by the proper co-ordination of surge arresters with the insulation. It is, therefore, recommended to use surge arresters if there are possibilities of lightning overvoltages or high switching overvoltages which may be dangerous to the equipment.

These surge arresters should constitute a reliable part of the system. They are designed to withstand the voltages and the resulting currents through them with a sufficiently high reliability taking into account pollution and other site matters. In each system such voltage stresses are (see IEC 71-1):

- operating voltage;
- temporary overvoltages;
- slow-front overvoltages;
- fast-front overvoltages;

where the slow-front overvoltages due to switching are of particular importance for arresters protecting range II equipment.

As a general principle, the best protection of equipment and high surge arrester rated voltages are contradicting requirements. Thus the selection of an adequate arrester constitutes an optimization process, which has to consider a great number of system and equipment parameters.

Gapless metal-oxide surge arresters are of particular advantage for earthed neutral systems, because they offer better protection against slow-front overvoltages. This arrester type is today widely installed in these systems and the application of arresters for such systems tends to concentrate on metal-oxide surge arresters. In some isolated or resonant earthed neutral systems, where earth fault temporary overvoltages may have long durations, gapped surge arresters may offer advantages, if protective levels are required to be low. While being the surge arrester traditionally used in all voltage ranges, the consideration of gapped arresters may be adequate for systems of range I, especially in the lower voltage range.

1.4 General procedure for the selection of surge arresters

The following iterative procedure, shown in the flow diagram of figure 1, is recommended for the selection of surge arresters:

- determine the continuous operating voltage of the arrester with respect to the highest system operating voltage;
- determine the rated voltage of the arrester with respect to the temporary overvoltages;

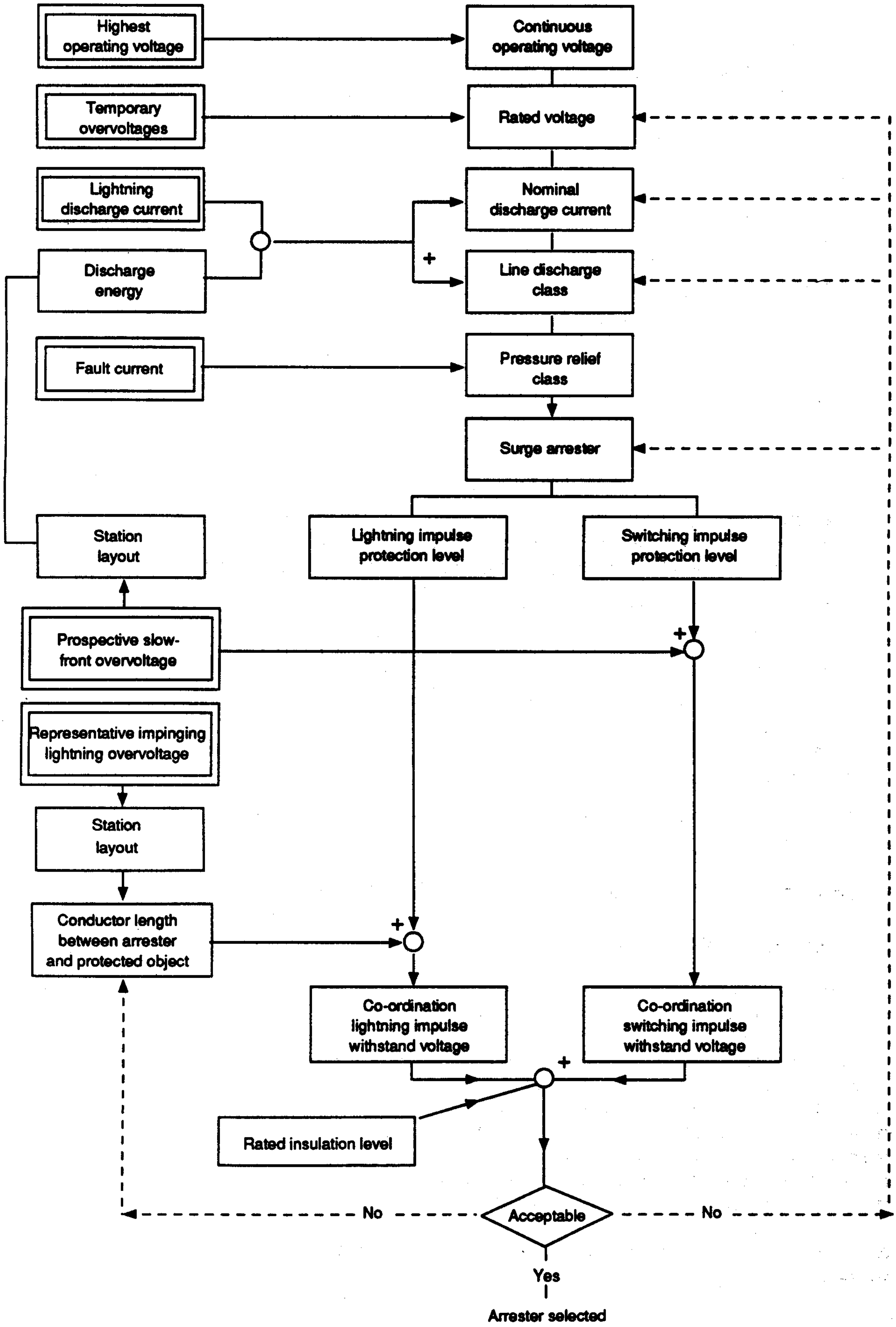
Highest operating voltage
Continuous operating voltage
Temporary overvoltages
Rated voltage
Lightning discharge current
Nominal discharge current
+
Discharge energy
Line discharge class
Fault current
Pressure relief class
Surge arrester
Station layout
Lightning impulse protection level
Switching impulse protection level
Prospective slow-front overvoltage
+
Representative impinging lightning overvoltage
Station layout
Conductor length between arrester and protected object
+
Co-ordination lightning impulse withstand voltage
Co-ordination switching impulse withstand voltage
+
Rated insulation level
No
Acceptable
No
Yes
Arrester selected

Figure 1 – Flow diagram for the selection of surge arresters

- estimate the magnitude and probability of the expected lightning discharge currents through the arrester, determine the transmission line discharge requirements and select the nominal discharge current, the high current impulse value and the line discharge class of the arrester;

NOTE – If high current impulse values different from the standardized values are necessary (see IEC 99-4, table 6, note), these values should be selected according to the lightning discharge current.

- select the pressure relief class of the arrester with respect to the expected fault current;
- select a surge arrester that fulfils the above requirement;
- determine the lightning and switching impulse protection characteristics of the arrester;
- locate the arrester as close as possible to the apparatus to be protected;
- determine the co-ordination switching impulse withstand voltage of the protected equipment taking into account the representative slow-front overvoltages and system layout;
- determine the co-ordination lightning impulse withstand voltage considering:
  - the representative impinging lightning overvoltage surge as determined by the lightning performance of the overhead line connected to the arrester and the acceptable failure rate of the protected equipment;
  - the substation layout;
  - the distance between surge arrester and protected equipment;
- determine the rated insulation level of the equipment from IEC 71-1;
- if a lower rated insulation level of the equipment is desired, then a lower continuous operating voltage, a lower rated voltage, a higher nominal discharge current, a higher line discharge class, a different arrester design or a reduced distance between arrester and protected object should be investigated.

NOTE – A lower continuous operating voltage or a lower rated voltage may reduce the service reliability of the arresters.

Details of this iterative procedure are given in sections 2, 3 and 4 of this document.

1.5 Polluted housing arrester withstand

Pollution on the arrester housing may cause sparkover or temperature increase of grading components in gapped arresters and high temperature increase of the varistors in metal-oxide arresters. To prevent arrester failures in polluted areas, arresters able to withstand the relevant polluted conditions have to be chosen. Although not explicitly specified in IEC 99-1 and IEC 99-4, arresters used in normal operating conditions should withstand the medium pollution stresses according to pollution level II of IEC 71-2. If the arrester installation area is subjected to a higher pollution, the surge arrester performance may be adversely affected. If arresters of inadequate design are used in heavy (pollution level III) or very heavy (pollution level IV) polluted areas, periodic cleaning or greasing may be effective in preventing the events stated above.

When live washing of arresters is intended, arresters designed for such service conditions are required.

Section 2: Non-linear resistor type gapped surge arresters according to IEC 99-1

2.1 Characteristic data of gapped surge arresters

2.1.1 *General*

Basic characteristics of surge arresters with series spark gaps are their rated voltage, their sparkover voltages, their nominal discharge currents and their residual voltages at these currents.

The protective performance is characterized by the sparkover voltages for front-of-wave, lightning impulse and, when applicable, switching impulses; and is also characterized by the residual voltages at nominal discharge current and, when applicable, at switching impulse currents. For a given rated voltage, different types of arresters and, therefore, different protection levels exist.

Additional characteristics of an arrester to be considered are continuous operating voltage, long duration discharge class, pressure relief class, pollution withstand capability, live washing capability and special mechanical properties.

2.1.2 *Rated voltage*

The maximum permissible r.m.s. value of the power frequency voltage between the arrester terminals, at which it is designed to operate correctly as established in the operating duty test. The rated voltage is used as a reference parameter for the specification of operating characteristics.

NOTE – Some types of arresters to be used in range II are designed to reseal at power frequency voltages higher than the rated voltage. This voltage is generally called the "temporary overvoltage reseal voltage". Since IEC 99-1 does not specify tests to assure the correct operation of such arresters, test details and application should be agreed between user and manufacturer.

In some cases, e.g. for the pollution test according to IEC 99-3, the maximum r.m.s. value of power frequency voltage which can be applied continuously between the arrester terminals should be known. For arresters to be used in range I according to IEC 71-1, this voltage may be equal to the rated voltage of the arrester. For arresters to be used in range II it is usually lower. As IEC 99-1 does not specify tests to assure this voltage, the applicable value should be obtained from the manufacturer.

2.1.3 *Protective levels*

The lightning impulse protective level of the surge arrester is the maximum of the following values:

- the standard lightning impulse sparkover voltage;
- the residual voltage at nominal discharge current.

NOTE – When considering the protection of equipment from fast front overvoltages it is assumed that the withstand strength of the oil-immersed insulation in the transformers is at least 15 % above its full lightning impulse withstand strength for voltage durations shorter than 3 µs. Therefore, the maximum voltages specified in IEC 99-1, table 8, for the front-of-wave sparkover are 15 % higher than those for the standard lightning impulse.

Other types of insulation as in instrument transformers, cables or gas insulated substations (GIS) may have different withstand characteristics and the front-of-wave sparkover voltage may need special consideration.

The switching impulse protective level is applicable to the protection of equipment from slow-front overvoltages. It is the maximum of the switching impulse sparkover voltage and the switching impulse residual voltage.

NOTE – When the switching impulse sparkover characteristic of an arrester type is not known, only approximate information about this is obtained from the power frequency sparkover voltage.

2.1.4 *Nominal discharge current*

The peak value of a discharge current having a 8/20 shape, which is used to classify an arrester. It is also the discharge current which is used to initiate the follow current in the operating duty test and to establish the protective level of the arrester for lightning overvoltages.

2.1.5 *Long duration discharge class*

A number related to the energy absorption capability of an arrester to discharge long lines. Increasing class numbers (see IEC 99-1, table 5) indicate increasing system voltages and line length and decreasing surge impedance and overvoltage factors.

2.1.6 *Pressure relief class*

A number related to the capability of an arrester to withstand internal fault currents after a failure without violent shattering of the housing. Reference is made to clause 8.7 of IEC 99-1.

2.1.7 *Pollution withstand characteristics*

For arresters to be used in polluted areas according to IEC 71-2, pollution levels III and IV, a pollution test according to IEC 99-3 is necessary. From this test, information about the sparkover performance is obtained. The flashover performance of the housing can be checked in accordance with IEC 507.

2.1.8 *Live washing characteristics*

Application of live washing may require a special arrester design and suitable tests have to be defined.

In the design of the washing equipment, care should be taken on the following points:

- water with an adequate resistivity must be used;
- the pressure and the nozzle configuration should be arranged so that the arrester in its whole length and circumference is wetted as uniformly and simultaneously as possible. For this it is necessary to consider the maximum permissible wind speed.

2.2 Selection of gapped surge arresters phase-to-earth

2.2.1 *Rated voltage*

It has been common practice to select an arrester to withstand the stresses due to the temporary overvoltages resulting from an earth fault on one phase causing a voltage rise on unfaulted phases at a time when an arrester operation occurs on one of these phases. Other causes of temporary overvoltages have to be considered and the voltage rating of the arrester should be chosen on the basis of the highest of these overvoltage conditions. In some cases it may be necessary to consider temporary overvoltages arising from the simultaneous occurrence of different phenomena such as sudden loss of load together with an earth fault, taking into account their probability of occurrence.

The following causes for temporary overvoltages should always be considered:

- Earth faults:

These overvoltages occur in a large part of the system. Guidance for the determination of temporary overvoltage amplitudes is given in annex A. The duration of the overvoltage corresponds to the duration of the fault (until fault clearing). In earthed neutral systems it is generally less than 1 s. In resonant earthed neutral systems with fault clearing it is generally less than 10 s. In systems without earth fault clearing the duration may be several hours.

- Load rejections:

After disconnection of loads, the voltage rises at the source side of the operating circuit breaker. The amplitude of the overvoltage depends on the disconnected load characteristics and on the short-circuit power of the feeding substation. The temporary overvoltages have particularly high amplitudes after full load rejection at generator transformers depending on magnetizing and overspeed conditions. The amplitude of load rejection overvoltages is usually not constant during its duration. Accurate calculations have to consider many parameters.

As a guidance, the following typical values may be used:

- In moderately extended systems, a full load rejection can give rise to phase-to-earth overvoltages with amplitude usually below 1,2 p.u. The overvoltage duration depends on the operation of voltage-control equipment and may be up to several minutes.
- In extended systems, after a full load rejection, the phase-to-earth overvoltages may reach 1,5 p.u. or even more when Ferranti or resonance effects occur. Their duration may be in the order of some seconds.
- For load rejection of generator transformers the temporary overvoltages may reach amplitudes up to 1,4 p.u. for turbo generators and up to 1,5 p.u. for hydro generators. The duration is approximately 3 s.

When the time dependence of the amplitudes is known, a suitable representation of the overvoltage is the maximum amplitude, with a duration equal to the time while the amplitudes exceed 90 % of this value.

In some systems the following causes of temporary overvoltages need consideration:

- resonance effects, e.g. when charging long unloaded lines or resonances between systems;
- voltage rise along long lines (Ferranti effect);
- harmonic overvoltages, e.g. when switching transformers;
- backfeed through interconnected transformer windings, e.g. dual transformer station with common secondary bus during fault clearing or single-phase switched three-phase transformer with an unbalanced secondary load.

Temporary overvoltages due to ferro-resonances should not form the basis for the surge arrester selection, but should be eliminated.

Combination of causes such as earth faults and load rejection may result in higher temporary overvoltage values than those from the single events. When such combinations are considered sufficiently probable, the overvoltages for each cause have to be compounded, taking into account the actual system configuration.

NOTES

1 The selection of the arrester rated voltage corresponding to the highest system temporary overvoltages is based on the assumption that the highest system voltage is not exceeded under normal operating conditions. If abnormal system voltages are likely to occur, thereby increasing the probability of arrester operations during such conditions, it may be necessary to use an arrester with a higher rated voltage than that recommended above.

2 Operating voltages with frequencies other than 50 Hz or 60 Hz may require special consideration in the manufacture or application of surge arresters and should be a subject of discussion between manufacturer and user.

Arresters for isolated or resonant earthed neutral systems without automatic earth fault clearing should be able to withstand the rated voltage continuously due to the possible long duration of the temporary overvoltage. Arresters for systems with automatic earth fault clearing need only withstand the maximum phase-to-earth system voltage. This reduced value can be obtained from the manufacturer.

2.2.2 *Nominal discharge current*

2.2.2.1 *Factors influencing the lightning discharge currents*

As a general rule, arrester currents due to lightning strokes are less than the stroke current. In the case of direct strokes to lines, travelling waves propagate in opposite directions from the point of impact. Flashover of line insulation provides a parallel path to ground, which diverts a portion of the stroke current. In the case of strokes to more than one conductor, or flashovers between conductors, two or more surge arresters may operate and share the current. Only in the case of a direct stroke very near to the terminal of the arrester, where no flashover occurs before arrester operation, is the arrester called upon to discharge most of the lightning stroke current. The probability of such an occurrence can be significantly reduced by proper shielding. Information concerning lightning surge parameters can be obtained from general statistical data or from local statistical data. The relationship between lightning surges and surge arresters discharge currents may be obtained from travelling wave calculations.

Overhead lines may be protected against direct lightning strokes to the conductors by the use of shield (overhead ground) wires, which are positioned to intercept lightning strokes and to direct the stroke current to ground via metallic tower or pole structures. Where wood-pole structures are used, low-impedance conductors are used to connect the shield wires to ground.

Almost all direct strokes to line conductors are eliminated by the use of shield wires. When such a direct stroke (shielding failure) does occur, line flashover is almost certain in range I. The number of shielding failures and their severity can be controlled by number and location of the shield wires. When a lightning stroke terminates on a shield wire, the stroke current is diverted to ground through the structure-connecting conductors. The impedance of the current path, including the ground surge impedance, results in a voltage at the top of the line structure. A portion of this voltage is coupled to the phase conductors. The difference between the phase conductor potential and structure top potential is impressed directly across line insulation and may result in flashover. This type of flashover is called a back-flashover. The rate of occurrence of back-flashovers is controlled by selection of a proper insulation level, by keeping the structure ground resistance to an acceptably low value by providing adequate clearance from conductor to structure, conductor to shield wire and conductor to conductor and by optimizing tower geometry.

Procedures analogous to those used for shielding lines may also be used for shielding stations. Shielding methods include overhead ground wires, metallic masts, and lightning rods supported from the station structure. These methods may be used in many combinations.

In installations not shielded against direct lightning strokes, for example at distribution transformers or cable junctions on wood-pole lines, both the insulation and the arrester can be subjected to direct strokes producing extremely high discharge currents. In general the lightning current and a representative discharge current shall be based on their probability of occurrence.

The purpose of shielding in station applications is to reduce the risk of insulation failure to an acceptable level. In certain applications this may be achieved by shielding the station alone. In other cases it may be necessary to shield all incoming lines to the station. Shielding of the lines for a relatively short distance from the station affords the same benefits for station protection as complete line shielding.

With well-designed shielding, insulation, and grounding systems, the probability of direct strokes to phase conductors is reduced to a low level and the voltages across insulation in the event of strokes to the shielding system are reduced below flashover levels. As a result, arrester discharge currents are reduced, thereby permitting the arrester to provide better protection to equipment insulation and reducing arrester duty.

2.2.2.2 *Selection of the nominal discharge current*

As a general rule, the nominal discharge current of an arrester is selected after considering:

- the importance and degree of protection desired. Basing protection levels on higher current magnitudes and rates-of-rise increases the reliability of protection;

- the number of lines connected during arrester operation. Owing to reflections of travelling waves, the discharge current of the arrester is affected by the parallel-connected surge impedance of lines and cables;

- the line insulation. The prospective lightning discharge currents increase with higher line insulations (e.g. fully insulated wood-poles), unless the stroke occurs so close to the arrester that the impedance and insulation of the line cannot influence the surge. When arresters are used in a station to which wood-pole lines with unearthed crossarms or insulator pins are connected, then at least one pole, preferably the last one in this line, should have earthed crossarms or pins, with low earthing impedance. In case of high earthing impedances several poles within a distance of about five spans from the station should be earthed;

- the probability of occurrence of the higher stroke currents. The magnitude of lightning currents varies over a wide range of values. Lines in areas of high lightning ground flash density have an increased chance of being struck by lightning with high current magnitudes;

- line performance and lightning environment. Lightning discharge currents and rates-of-rise are functions of the back-flashover and shielding failure rates of the lines (or flashover rates of unshielded lines) which are within some limiting distance from the station. Higher (lower) failure rates increase (decrease) the probable lightning discharge current magnitude and rate-of-rise.

For the standard nominal discharge currents according to IEC 99-1, experience indicates that a satisfactory degree of protection is achieved if the following recommendations are observed.

Range I (above 1 kV to 245 kV): 5 kA or 10 kA

In systems in range I of IEC 71-1 where the line distances between arresters are small (below 5 km), surge arresters at distribution transformers with a nominal discharge current of 5 kA have proven sufficiently reliable, even when the transformers are connected to wood-pole lines with unearthed cross-arms.

In systems with highest voltages of 72,5 kV and below, surge arresters with a nominal discharge current of 5 kA may be sufficient for areas with low ground flash density and effectively shielded incoming overhead-lines with low tower footing impedances. Arresters with a nominal discharge current of 10 kA may be preferable for important installations (need for the best protection) particularly in areas with high lightning flash density or high earth resistances.

In systems with highest voltages above 72,5 kV, surge arresters with a nominal discharge current of 10 kA are generally recommended.

Range II: (above 245 kV): 10 kA or 20 kA

For systems with highest voltages of 420 kV and below, surge arresters with a nominal discharge current of 10 kA are generally sufficient.

For systems with highest voltages above 420 kV, 20 kA arresters may be required.

2.2.3 *Long duration discharge capability*

In installations where long lines or cables or high capacitances are connected, the arrester must be capable of withstanding the discharge current and energy due to switching overvoltages. For heavy duty 10 kA arresters, therefore, test data have been specified for various ranges of system voltages (see 8.5.3 of IEC 99-1), which represent typical energy dissipation through arresters in the system concerned. Heavy duty arresters are generally used for equipment of range II. For equipment of range I, heavy duty arresters are used in case of important stations, in case of required low protective levels or in case of long overhead lines, cables or capacitor banks connected to the busbar. For other cases, e.g. where incoming lines are relatively short (less than 100 km), 10 kA light duty arresters or 5 kA arresters are generally used.

2.2.3.1 *Heavy duty arresters*

The test requirements shown in table 5 of IEC 99-1 are based on the duty involved in discharging transmission lines and on an arrester rating equal to 1,4 times the highest system voltage phase-to-earth.

Normally, the long duration discharge class is based on the corresponding system voltage, see table 1. However, where line characteristics vary appreciably from those in table 1, the energy dissipated in the arrester during service conditions has to be compared with that in the test according to table 1. In such cases, a study of the particular circumstances is recommended.

Table 1 – Relationship between long duration discharge class and transmission line characteristics (see table C.1 of IEC 99-1)

Long duration discharge class	Approximate range of highest system voltages kV	Approximate line length km	Approximate line surge impedance Ω	Approximate overvoltage factor (p.u.)*
1	Up to 245	300	450	3,0
2	Up to 300	300	400	2,6
3	Up to 420	360	350	2,6
4	Up to 525	420	325	2,4
5	Up to 765	480'	300	2,2

* The base for the per unit values is the peak value of the highest system voltage phase-to-earth.

2.2.3.2 *Light duty 10 kA and 5 kA arresters*

For light duty 10 kA and for 5 kA arresters, no differentation of system voltages is made but only one test current with rectangular wave shape is specified.

2.2.4 *Pressure relief class*

In case of internal failure of a surge arrester, the fault current through the arrester should not cause violent shattering of the arrester housing. Therefore the fault current withstand of the arrester should be equal to or greater than the maximum fault current through the arrester at the installation point of the arrester.

If higher values than those listed in table 7 of IEC 99-1 are required, the user should consult the manufacturer.

Section 3: Gapless metal-oxide surge arresters according to IEC 99-4

3.1 Characteristic data of gapless metal-oxide surge arresters

3.1.1 *General*

Basic characteristics of metal-oxide surge arresters are the continuous operating voltage, the rated voltage, the nominal discharge current and the residual voltages at nominal discharge current, at switching impulse current and at steep front current.

For given continuous operating and rated voltages, different types of arresters, and therefore different protection levels, exist.

Further characteristics which have to be considered in a particular application are line discharge class, pressure relief class, pollution withstand capability, live washing capability and special mechanical properties.

3.1.2 *Continuous operating voltage*

The continuous operating voltage is the maximum permissible value of a sinusoidal power frequency voltage, which may be continuously applied between the arrester terminals.

The continuous operating voltage of the complete arrester may be lower per section than that used in the operating duty test, for the ageing procedure, and for verifying thermal stability. The lower continuous operating voltage may be due to the pollution strength of the arrester housing or to large non-linearities in the voltage distribution along the varistor stack due to less effective grading caused by proximity effects of other objects.

3.1.3 *Rated voltage*

The rated voltage is the maximum power frequency voltage that is applied in the operating duty test for 10 s (see clause 2.8 of IEC 99-4). It is, furthermore, the reference parameter to establish the power frequency voltage versus time characteristic of the arrester, and for defining the test requirements for the line discharge test.

3.1.4 *Nominal discharge current*

The nominal discharge current is used for the surge arrester classification. It is the main parameter for the protective characteristics and the energy absorption capability of the arrester.

3.1.5 *Protective levels*

The lightning impulse protective level of an arrester is the maximum residual voltage at nominal discharge current. It is applicable to the protection of equipment from fast-front overvoltages.

The switching impulse protective level is the maximum residual voltage at the specified switching impulse currents. It is applicable to the protection of equipment from slow-front overvoltages.

For the protection performance of metal-oxide surge arresters for fast-front overvoltages the time delay in the conduction mechanism of the varistors as tested in the steep current impulse test has to be considered [2]*.

NOTE – In the first edition of IEC 99-4:1991, the necessary test procedure for a reliable determination of the residual voltage at steep current impulse has been incompletely specified. More precise specification of test conditions is under consideration which will take care of inductance effects and the intrinsic material time delay.

3.1.6 *Line discharge class*

A number related to the energy absorption capability of 10 kA and 20 kA arresters for the discharge of long lines. Five classes exist according to IEC 99-4, table 4, with an increasing number indicating increased energy absorption capability.

For arresters with line discharge class 2 and above, the resulting discharge current is used in the operating duty test to verify thermal stability after energy absorption. System events causing arrester currents with different shapes may be evaluated by comparison with energy and current of an equivalent line discharge.

3.1.7 *Pressure relief class*

A number related to the capability of an arrester to withstand internal fault currents without violent shattering of the housing. (Reference is made to clause 5.11 of IEC 99-4 and clause 8.7 of IEC 99-1.)

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* Numbers in brackets refer to annex C: Bibliography.

3.1.8 *Pollution withstand characteristics*

The pollution withstand capability of the arrester concerns three aspects:

a) the arrester housing has to withstand the pollution stresses without flashover. This can be verified according to IEC 507 or is assured by a design according to IEC 815;

b) the arrester has to withstand the possible temperature increase due to the changes in voltage distribution caused by the pollution activity on the surface of the housing. Consideration should be given to the pollution level and the frequency and amplitude of overvoltages caused by faults and reclosing operations during polluted conditions. Suitable test procedures are under consideration;

c) the arrester has to withstand internal partial discharges, caused by disturbed voltage grading on the housing due to pollution, without damage to the varistors or to the internal mounting elements. Possible test procedures are under consideration.

3.1.9 *Live washing characteristics*

When live washing of the arrester is foreseen, assurance is required that the arrester housing will not flash over and that the temperature increase of the varistors remains within the specified maximum temperature. Suitable test procedures have to be defined.

3.2 Selection of gapless metal-oxide surge arresters phase-to-earth

3.2.1 *Continuous operating voltage*

The basic requirement is that the peak of the continuous operating voltage of the surge arrester must be higher than the peak of the operating voltage. The peak of the operating voltage is determined by the power frequency voltage corresponding to the highest voltage of the system and by possible voltage harmonics. In usual systems, the increase of the peak voltage by harmonics can be taken into account by a safety factor of 1,05 to the power frequency voltage. As a general rule, the continuous operating voltage should be:

- in systems with automatic earth fault clearing, equal to or higher than the peak value of the highest operating voltage phase-to-earth divided by $\sqrt{2}$;
- in resonant earthed or isolated neutral systems without automatic earth fault clearing, equal to or higher than the highest operating voltage.

NOTE – For these systems the safety factor of 1,05 has been considered to be covered by the power frequency voltage versus time characteristic of the arrester taking into account the limited duration of the earth fault in these systems.

If the highest operating voltage at the arrester location is not accurately known, it should be replaced by the highest voltage of the system or by the highest voltage for equipment.

If the arrester is installed closer to live or earthed objects than recommended by the manufacturer, it has to be investigated whether the voltage distribution along the arrester is sufficiently linear for the selected continuous operating voltage.

3.2.2 *Rated voltage*

The rated voltage of the arrester is selected based on the temporary overvoltages in the system at the arrester location, considering their amplitudes as well as their durations. The basic requirement is that the power frequency voltage versus time characteristic of the arrester should be higher than the temporary overvoltage amplitude versus duration characteristic of the system. Pollution withstand capability and live washing capability should be considered when appropriate.

The following causes of temporary overvoltages should always be considered:

- Earth fault overvoltages

  These overvoltages occur in a large part of the system. Guidance for the determination of temporary overvoltage amplitudes is given in annex A. The duration of the overvoltage corresponds to the duration of the fault (until fault clearing). In earthed neutral systems it is generally less than 1 s. In resonant earthed neutral systems with fault clearing it is generally less than 10 s. In systems without earth fault clearing the duration may be several hours.

- Load rejections

  After disconnection of loads the voltage rises at the source side of the operating circuit breaker. The amplitude of the overvoltage depends on the disconnected load and on the short-circuit power of the feeding substation. The temporary overvoltages have particularly high amplitudes after full load rejection at generator transformers depending on magnetizing and overspeed conditions. The amplitude of load rejection overvoltages is usually not constant during its duration. Accurate calculations have to consider many parameters.

  As a guidance the following typical values of such overvoltages may be used [1]

  - In moderately extended systems, a full load rejection can give rise to phase-to-earth overvoltages with amplitude usually below 1,2 p.u. The overvoltage duration depends on the operation of voltage-control equipment and may be up to several minutes.

  - In extended systems, after a full load rejection, the phase-to-earth overvoltages may reach 1,5 p.u. or even more when Ferranti or resonance effects occur. Their duration may be in the order of some seconds.

  - For load rejection of generator transformers the temporary overvoltages may reach amplitudes up to 1,4 p.u. for turbo generators and up to 1,5 p.u. for hydro generators. The duration is approximately 3 s.

  When the time dependence of the amplitudes is known, a suitable representation of the overvoltage is the maximum amplitude, with a duration equal to the time while the amplitudes exceed 90 % of this value.

In some systems the following causes of temporary overvoltages need consideration:

- resonance effects, e.g. when charging long unloaded lines or resonances between systems;

- voltage rise along long lines (Ferranti effect);

- harmonic overvoltages, e.g. when switching transformers;
- backfeed through interconnected transformer windings, e.g. dual transformer station with common secondary bus during fault clearing or single-phase switched three-phase transformer with an unbalanced secondary load.

Temporary overvoltages due to ferro-resonances should not form the basis for the surge arrester selection and should be eliminated.

Sequences of causes for temporary overvoltages, e.g. load rejection caused by an earth fault, need consideration, when both overvoltages have comparable severity. In such cases, however, the amount of rejected load dependent on the fault location and the arrester location has to be carefully examined.

Combination of causes such as earth faults and load rejection may result in higher temporary overvoltage values than those from the single events. When such combinations are considered sufficiently probable, the overvoltages for each cause have to be compounded taking into account the actual system configuration.

The power frequency voltage versus time characteristic of the arrester should exceed the temporary overvoltage amplitude versus duration of the system. As an approximation, amplitude and duration of temporary overvoltages, the duration of which is between 0,1 s and 100 s, can be converted to an equivalent amplitude, U_{eq}, with a duration of 10 s (corresponding to the duration of the rated voltage in the operating duty test):

$$U_{eq} = U_t \left(\frac{T_t}{10}\right)^m \quad (1)$$

where

U_t is the amplitude of the temporary overvoltage;

T_t is the duration of the temporary overvoltage in s;

U_{eq} is the amplitude of the equivalent 10 s temporary overvoltage; and

m is the exponent describing the power frequency voltage versus time characteristic of the arrester. For different arrester designs the exponent varies between 0,022 and 0,018 and an average value of 0,02 may be used.

The rated voltage of the arrester should be equal to or higher than the highest equivalent temporary overvoltage obtained.

NOTES

1 In some applications a safety margin is applied between maximum equivalent temporary overvoltage and rated voltage in order to cover possible inaccuracies in the determination of the overvoltage. Usual values of such margins are between 5 % and 15 %.

2 When protective levels lower than that of the adopted arrester design are desired, rated voltages below the equivalent 10 s temporary overvoltages may be selected, provided the arrester is able to absorb the energy caused by system events. In this case energy absorption calculations should be carried out simulating the system events. Besides careful system representations the production dispersion of the voltage-current characteristic of the arrester should be considered.

3 In some cases, the rated voltage of the arrester is also selected considering the energy absorption during the transmission line discharge with the disadvantage of a higher protective level of the arrester.

3.2.3 *Nominal discharge current and line discharge class*

3.2.3.1 *General*

In IEC 99-4 the energy absorption capability of the arrester is linked to the nominal discharge current. If the high current impulse value is not chosen from table 6 of IEC 99-4 (as is allowed according to note 1 to the table), the energy absorption capability of the arrester is related to the nominal discharge current and to the high current impulse. Furthermore, the energy absorption of the arrester, due to a system transient overvoltage stress, depends on the residual voltage-current characteristic of the arrester and thus on the nominal discharge current. Nominal discharge current and line discharge class, therefore, are determined in an iterative process.

3.2.3.2 *Nominal discharge current*

The nominal discharge current is selected according to the lightning discharge current through the arrester, for which protection of equipment is desired. The same considerations as for the gapped arrester in 2.2.2 apply. As a general rule, the following values are suitable depending on the expected lightning discharge current:

Range I: (above 1 kV to 245 kV): 5 kA or 10 kA

In systems in range I of IEC 71-1 where the line distances between arresters are small (below 5 km), surge arresters at distribution transformers with a nominal discharge current of 5 kA have proven sufficiently reliable, even when the transformers are connected to wood-pole lines with unearthed cross-arms.

In systems with highest voltages of 72,5 kV and below, surge arresters with a nominal discharge current of 5 kA may be sufficient for areas with low ground flash density and effectively shielded incoming overhead-lines with low tower footing impedances. Arresters with a nominal discharge current of 10 kA may be preferable for important installations (need for the best protection) particularly in areas with high lightning flash density or high earth resistances.

In systems with highest voltages above 72,5 kV, surge arresters with a nominal discharge current of 10 kA are generally recommended.

Range II (above 245 kV): 10 kA or 20 kA

For systems with highest voltages of 420 kV and below, surge arresters with a nominal discharge current of 10 kA are generally sufficient.

For systems with highest voltages above 420 kV, 20 kA arresters may be required.

3.2.3.3 *Energy absorption capability*

Metal-oxide surge arresters must be able to absorb the energy due to transient overvoltages in the system. Severe transient overvoltages are those arising from:

- closing or reclosing long lines;
- disconnection of capacitor banks or cables with restriking circuit breakers;

- lightning strokes to overhead line conductors with high insulation level or back-flashovers close to the arrester location.

With known protection levels of the arrester, the energy to be absorbed by the arrester can be estimated using the formulae below [3, 4]:

- closing and reclosing of lines

$$W = 2U_{ps}(U_e - U_{ps})\frac{T_w}{Z} \tag{2}$$

where

W is the energy absorption;
U_{ps} is the switching impulse protection level of the arrester;
U_e is the overvoltage amplitude, e.g. estimated according to IEC 71-2;
Z is the surge impedance of the line;
T_w is the travel time along the line equal to length divided by wave velocity of the line;

- capacitor or cable switching

$$W = \frac{1}{2} C[(3U_o)^2 - (\sqrt{2}U_r)^2] \tag{3}$$

where

C is the capacitance of the bank or the cable;
U_o is the phase-to-earth operating voltage peak;
U_r is the rated voltage of the arrester (r.m.s. value).

The energy may be shared with other arresters on the same phase. Degree of sharing should be studied.

- lightning

$$W = [2U_f - NU_{pl}(1 + \ln(2U_f / U_{pl}))]\frac{U_{pl}T_l}{Z} \tag{4}$$

where

ln is the *natural logarithm;*
U_{pl} is the lightning impulse protection level of the arrester;
U_f is the negative flashover voltage of the line insulation;
Z is the line surge impedance;
N is the number of lines connected to the arrester;
T_l is the equivalent duration of the current of a lightning flash including first and subsequent strokes. Typical value $3 \cdot 10^{-4}$ s.

If the distances between stations in distribution systems are small, the energy can be divided because of current sharing.

NOTE – The formula has been derived from an integration of an exponentially decreasing overvoltage.

In some cases events other than those mentioned may result in a large energy absorption by the gapless arrester. A typical example is the operation of current limiting fuses in an unusual application, e.g. if the fuse rating is much higher than required for the system application, or if arresters with very low protective level are installed.

In the operating duty test (clause 7.5 in IEC 99-4) the arrester has to absorb the following energy prior to the application of the rated voltage:

- 5 kA and 10 kA, line discharge class 1 arresters

  These arresters are subjected to a high current impulse operating duty test. The energy produced by the high current impulse can be estimated by [3]:

$$W = U_a I T \tag{5}$$

where

U_a is the residual voltage at this high current impulse. If this is not known, it may be estimated as 1,5 times the residual voltage at nominal discharge current;

I is the amplitude of the specified high current impulse;

T is the effective time of the high current impulse = 6,5 µs;

- 10 kA, line discharge class 2 or above, and 20 kA arresters.

  These arresters are subjected to a switching surge operating duty test. The absorbed energy per impulse is given in annex E of IEC 99-4. The energy absorption capability of the arrester is equal to or larger than twice this value.

For a more accurate determination of the energy absorption, detailed digital studies should be carried out considering all parameters of the overvoltages.

If the energy absorption required for service is higher than the energy absorption capability of the selected arrester proven by the operating duty test, a higher nominal discharge current or a higher line discharge class or a higher high current impulse value should be selected. Alternatively, the rated voltage of the arrester may be increased, provided adequate protection is achieved.

3.2.4 *Pressure relief class*

In case of internal failure of a surge arrester, the fault current through the arrester should not cause violent shattering of the arrester housing. Therefore the fault current withstand of the arrester should be equal to or greater than the maximum fault current through the arrester at the installation point of the arrester.

If higher values than those listed in table 7 of IEC 99-1 and clause 5.11 of IEC 99-4 are required, the user should consult the manufacturer.

Section 4: Application of arresters

4.1 Principle of insulation co-ordination

The principle of insulation co-ordination according to IEC 71-1 and IEC 71-2 requires the determination of the rated withstand voltages in four steps:

a) Representative overvoltage at the equipment.

b) Co-ordination withstand voltage of the equipment during its service life.

c) Required withstand voltage of the equipment at standard test conditions. This may differ from the co-ordination withstand voltage due to insulation ageing or due to production and assembly dispersion. These differences are compensated by a safety factor of 1,15. For installation at altitudes up to 1 000 m, this factor also covers the necessary atmospheric correction for the external insulation.

d) Rated withstand voltage. This recognizes the possible different shapes of required and rated withstand values and includes the selection from tables of standardized values.

4.2 Protection from slow-front overvoltages

Protection from slow-front overvoltages is of high importance in range II. In range I, the standard insulation level of the equipment is usually so high that protection from slow-front overvoltages is not generally necessary (exceptions are rotating machines, see clause 5.3).

The representative overvoltage at the equipment protected by arresters is equal to the switching impulse protection level, because, with the exception of transmission lines, travelling wave effects can be neglected and the voltage at the equipment is equal to that at the arrester.

Metal-oxide arresters without gaps are suitable to protect against slow-front overvoltages in systems with moderate temporary overvoltages, whereas gapped arresters operate at slow-front overvoltages only after sparkover of the series gap. As a general rule, it can be assumed that with metal-oxide arresters, a limitation of the phase-to-earth overvoltage amplitudes (peak value) to approximately twice the arrester rated voltage (r.m.s. value) is possible. The protective level of gapped arresters is substantially higher.

This means that metal-oxide surge arresters are suitable for limiting slow-front overvoltages due to line energization and re-energization and switching of inductive and capacitive currents, but not in general overvoltages caused by earth faults and fault clearing, as the expected amplitudes of the latter are too low.

Overvoltages originating from line energization and re-energization give currents of about 0,5 kA to 2 kA through the arresters. In this current range the knowledge of the exact current amplitude is not so important due to the extreme non-linearity of the metal-oxide material. The influence on the current front times can be ignored for slow-front overvoltages. Furthermore, separation effects within substations can be neglected. Distant overhead line insulation, however, may be stressed by overvoltages substantially higher than the protective level.

Surge arresters are usually installed phase-to-earth and, if metal-oxide arresters are used to limit slow-front overvoltages to a low level, the phase-to-phase overvoltages will reach about twice the protection level of the arrester phase-to-earth, irrespective of the transformer neutral treatment. The phase-to-phase overvoltage will consist of two phase-to-earth components with the most frequent subdivision 1:1. If lower phase-to-phase protective levels are required, additional arresters phase-to-phase are needed.

The assumed maximum value of the representative phase-to-earth overvoltage is equal to the protection level of the surge arrester. For the phase-to-phase overvoltages, it can be up to twice this value without phase-to-phase arresters.

In the case of surge arrester protection against switching overvoltages, a severe skewing in the statistical distribution of overvoltages takes place. This skew is more pronounced the lower the protection level, as compared to the amplitudes of the prospective slow-front overvoltages. In these situations, small variations of the insulation withstand have a large impact on the risk-of-failure [2]. To cover this effect, it is proposed to determine the deterministic co-ordination factor dependent on the relation of the surge arrester protective level to the 2 % value of the prospective overvoltages.

$$\frac{U_{ps}}{U_{e2}} \leq 0,7 \quad : \quad K_{cd} = 1,1 \tag{6}$$

$$0,7 < \frac{U_{ps}}{U_{e2}} \leq 1,2 \quad : \quad K_{cd} = 1,24 - 0,2\,\frac{U_{ps}}{U_{e2}} \tag{7}$$

$$1,2 < \frac{U_{ps}}{U_{e2}} \quad : \quad K_{cd} = 1,0 \tag{8}$$

and the co-ordination switching impulse withstand voltage as

$$U_{cw} = K_{cd} \cdot U_{ps} \tag{9}$$

where

U_{ps} is the switching impulse protective level of the arrester;

U_{e2} is the 2 % value of the prospective slow-front overvoltage amplitude to earth;

U_{cw} is the co-ordination switching impulse withstand voltage of the equipment;

K_{cd} is the deterministic co-ordination factor.

NOTE – The factor 1,0 to 1,1 takes into account the high frequency of overvoltages with amplitudes equal to the protection level due to the truncation of the overvoltage distribution by the arrester. This frequency is higher, the lower the protective level. Due to the uncertainties in the equipment withstand, the margin between the withstand voltage and the protective level should increase with increasing overvoltage frequency to maintain a given risk level [2].

4.3 Protection from lightning overvoltages

4.3.1 *General*

Due to the high rate-of-rise of lightning overvoltages, travelling wave effects between arrester and equipment cannot be neglected. As a general rule, the voltage at the protected equipment is higher than the arrester residual voltage (see 4.3.2). Therefore, it is always good practice to reduce conductor separation distance between arrester and major equipment to a minimum. However, it is sometimes possible to protect more than one piece of equipment with a single arrester installation provided that rates of rise can be limited as in the case where both the station and overhead feeder lines are effectively shielded.

A major factor in locating arresters within a station is the line and station shielding. It is usually feasible to provide shielding for the substation even though the associated lines are unshielded. Station shielding reduces the probability of high voltages and steep wave fronts within the station resulting from high-current lightning strokes. However, it should be recognized that the majority of strokes will be to the lines, which will create surges that travel along the line and into the station. If the lines are shielded, the surges entering the station are less severe than those from unshielded lines. Consequently, the magnitude of the arrester currents is lower, resulting in lower arrester residual voltage and better protection of the equipment.

Unshielded installations are subjected to the highest lightning currents and voltage rates of rise. The very minimum possible separation is recommended for installations where complete shielding is not used.

In shielded installations with a single unshielded incoming overhead line, the arrester should be located as near as possible to the terminals of the equipment (usually a transformer) to be protected. When several unshielded incoming overhead lines meet in the station, the incoming overvoltage amplitude and steepness are reduced by division but their frequency of occurrence is increased. However, consideration should be given to the case when one or more of the lines are switched out of service and the probability of such contingencies during lightning storms should be considered. When one or more circuit breakers or disconnecting switches are open in such a station, the corresponding line entrances or certain parts of the station may be left without protection from the arresters at the transformers. Lightning flashover of a de-energized line is unlikely to cause damage to line insulation, but insulation in other equipment such as circuit breakers, voltage transformers and current transformers connected on the line side might be damaged. If such cases are recognized to require additional protection, arresters can be installed at the respective line entrances.

Incoming voltages from shielded lines are lower in amplitude and steepness than from unshielded lines. In many cases, this will permit some separation between the arresters and the insulation to be protected. With a single shielded incoming overhead line, one set of arresters may be located at a point that provides protection to all equipment but gives preference to the transformer. The method in 4.3.2. can be used to determine the maximum separation distance between the arrester and the transformer.

At stations with multiple shielded incoming overhead lines (associated with large installations with transformers, switchgear and measuring equipment), arresters are not always placed at the terminals of every transformer. The methods described in 4.3.2 can be used to estimate maximum separation distances. More important installations may justify a detailed transient study. Such studies and interpretation of their results are outside the scope of this standard.

Two alternatives exist in the application of surge arresters for the lightning overvoltage protection of equipment:

- determine the necessary co-ordination lightning impulse withstand voltage for given arrester protection level and separation distance. The rated lightning impulse withstand voltage is then obtained by multiplying the obtained value by the factor of 1,15 (see clause 4.1);
- determine the protective zone of the arrester which is the maximum separation distance for which the insulation co-ordination requirements are fulfilled, for given arrester protective level and co-ordination withstand voltage. This is obtained by dividing the rated lightning impulse withstand voltage of the equipment by 1,15 (see clause 4.1).

In principle, both alternatives require the determination of the actual overvoltage shape at the protected equipment and its withstand voltage associated with this shape. As a sufficiently adequate simplification, however, it can be assumed that this requirement is covered under the following conditions:

- for gapped surge arresters:

  the front-of-wave sparkover voltage is compared with the chopped lightning impulse withstand voltage of the equipment;

  and/or

  the lightning impulse sparkover voltage and the residual voltage at nominal discharge current (8/20) are compared with the lightning impulse withstand voltage of the equipment.

  For oil-paper insulated transformers, both alternatives give approximately the same result. Furthermore, for large transformers the input capacitance reduces the rate-of-rise of the impinging overvoltage. Therefore, the consideration of the front-of-wave sparkover may be omitted.

  If the equipment at the line entrance of the substation has chopped lightning impulse withstand strength less than 15 % above full impulse, then consideration of the front-of-wave sparkover voltage may be necessary.

  For gas insulated substations the transmitted and reflected waves within the substation cause a decrease of the rate-of-rise of the impinging surge causing sparkover of the arrester at voltages lower than the front-of-wave sparkover voltage. As a simplification, therefore, the effects of the front-of-wave sparkover of the arrester may be neglected or, alternatively, travelling wave calculations may be performed.

- for gapless metal-oxide surge arresters:

the residual voltages at nominal discharge current and/or at steep current impulse are compared with the lightning impulse withstand voltage of the equipment.

The representative lightning overvoltages for which protection is desired usually cause currents through the arrester which have front times closer to 1 μs than to 8 μs. The use of the residual voltage at steep current impulse, therefore, may be justified which would result into approximately 5 % higher overvoltage than those using the residual voltage at nominal discharge current. Comparison calculations have shown that this effect is similar to that of the front-of-wave sparkover of gapped silicon carbide arresters and the same considerations apply.

NOTE – For air insulation, these procedures may result in a too conservative result owing to the delay in the insulation flashover, which is usually expressed as voltage-time curves. More accurate results may be obtained from travelling wave calculations, in which this flashover delay is taken into account. Similar considerations apply to other insulations for which the breakdown behaviour is known.

4.3.2 *Simplified method for lightning protection*

4.3.2.1 *Protection of open air equipment*

Experience with existing substation equipment has shown that, if the influencing factors given in 4.3.1 are taken into account, the co-ordination lightning impulse withstand voltage can be determined from empirical formula (10) which considers the fundamental characteristics of lightning overvoltage behaviour in stations (see IEC 71-2).

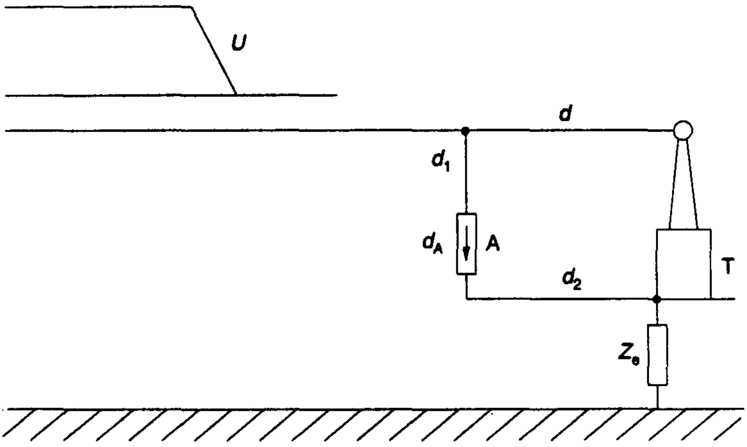


Figure 2a – Installations without earth-mat (distribution systems)

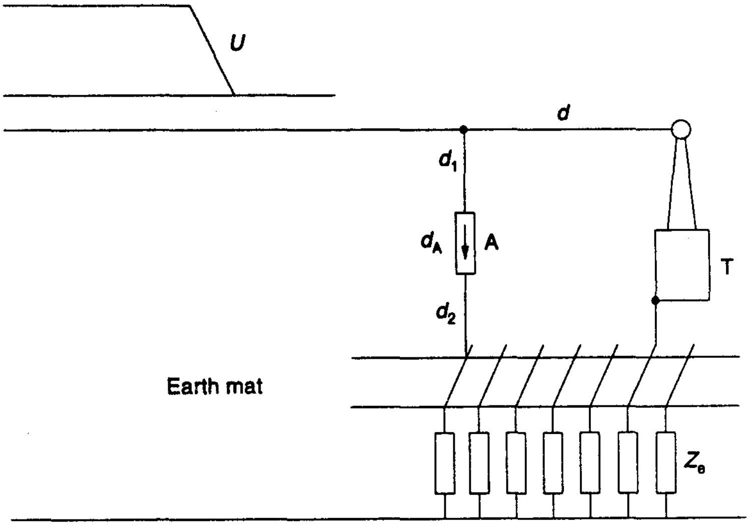


Figure 2b – Installations with earth mat (substations)

Figure 2 – Schematic diagram for the surge arrester connection to the protected object

where

d is the distance between the high-voltage terminal of the protected equipment and the connection point of the arrester high-voltage conductor;

d_1 is the length of the arrester high-voltage conductor;

d_2 is the length of the arrester earth conductor;

d_A is the length of the arrester;

Z_e is the earthing impedance;

T is the protected object;

U is the impinging overvoltage surge.

$$U_{cw} = U_{pl} + \frac{A}{N} \times \frac{L_t}{L_{sp} + L_f} \qquad (10)$$

where

$L_f = R_a / r$ is the length of the overhead line in front of the station, which gives a rate of lightning events equal to the acceptable failure rate. The right fraction multiplied by A/N is proportional to the steepness of the representative impinging surge. Note that in formulas (10), (11) and (12) consistent units must be used;

U_{cw} is the co-ordination lightning impulse withstand voltage;

A is the voltage according to table 2 describing the lightning performance of the overhead line connected to the station;

U_{pl} is the lightning impulse protection level of the surge arrester;

N is the number of lines connected to the substation ($N = 1$ or $N = 2$);

L_t is the total length $d + d_1 + d_2 + d_A$, figure 2;

L_{sp} is the span length;

L_f is the overhead line section with outage rate equal to acceptable failure rate;

R_a is the acceptable failure rate (number of failures per unit time) for the protected equipment;

r is the overhead line outage rate (number of outages per unit time and unit length) per year for a design corresponding to the first kilometer in front of the station. If $N = 2$, the rates have to be added.

Usual acceptable failure rates of the protected equipment are, as stated in IEC 71-2, between 0,1 % per year and 0,4 % per year. A typical value of 0,25 % per year is used in the examples of table 3.

For distribution lines the outage rates are usually large compared to the acceptable failure rates, i.e. the overhead line length L_f is small and can be neglected. Formula (10) is then simplified to:

$$U_{cw} = U_{pl} + \frac{A}{N} \times \frac{L_t}{L_{sp}} \qquad (11)$$

Induced lightning overvoltages need to be considered in distribution systems, where the equipment is not protected against direct lightning strokes to the conductors or against back-flashovers. (Detailed recommendations are under consideration within CIGRE.)

NOTE – Formula (10) describes the p.u. voltage drop depending on the lightning performance of the overhead line connected to the equipment, on the substation layout and on the adopted acceptable failure rate of the equipment. Using the existing knowledge of the lightning performance of overhead lines and of corona damping effects, the constant A has been determined to obtain agreement between the withstand voltages calculated with formula (10) and the service experience obtained with protective zones used for a long time (see table 3). The formula may not be used to determine overvoltage amplitudes for a specific lightning event on the overhead line.

When the rated lightning impulse withstand voltage of the equipment is selected, the protective zone of the arrester can be estimated from formula (12):

$$L_p = \frac{N}{A}\left[\left(\frac{U_{rw}}{1,15}\right) - U_{pl}\right](L_{sp} + L_f) \qquad (12)$$

where

L_p is the protective zone;

U_{rw} is the rated lightning impulse withstand voltage (see clause 4.1).

Formula (12) indicates that for a given substation the protective zone increases with:

- increasing difference between rated withstand voltage and protective level;

- decreasing outage rate of the overhead line in front of the station, thus demonstrating the effect of improved shielding by earth wires and reduced tower footing impedance;
- increasing acceptable failure rates, which means that the equipment outside the protective range still may be protected, however with a higher failure rate.

Table 3 shows examples for calculated protective zones, in which the underlined ranges are those generally adopted. The protective zones 160 m and 180 m are supported by experience with line entrance equipment protected by the arrester at the transformer, when perfect shielding of the overhead line in front of the station is provided.

Table 2 – Factor *A* in formulas (10) to (12) for various overhead lines

	A kV
Distribution lines (phase-to-phase flashovers)	
– with earthed cross-arms (flashover to earth at low voltage)	900
– wood-pole lines (flashover to earth at high voltage)	2 700
Transmission lines (single-phase flashover to earth)	
– single conductor	4 500
– double conductor bundle	7 000
– four conductor bundle	11 000
– six and eight conductor bundle	17 000

NOTE – The voltages *A* for distribution lines are lower than that for the single conductor transmission line, because in distribution lines phase-to-phase flashovers or multiple phase-to-earth flashovers occur, thus leading to current sharing, and in case of earthed cross-arms, to a limitation of the incoming surge amplitude.

Table 3 – Examples for protective zones calculated by formula 10 for open air substations

System voltage	Protection level	Withstand voltage		Span	A	Protective zone L_p					
						$r = 0,1$*	$r = 0,5$*		$r = 2$*		$r = 6$*
		rated	co-ordination			$N = 2$	$N = 1$	$N = 2$	$N = 1$	$N = 2$	$N = 2$
kV	kV	kV	kV	m	kV						
24	80	125	109	100	2 700	—	—	—	2,4	4,8	3,0
				200	900	—	—	—	10,4	20,8	15,5
123	350	550	478	300	4 500	160	23	46	12,0	24	—
420	900	1 425	1 239	400	11 000	180	28	56	16	32	—

* Dimensions in 1 per 100 km and year.

4.3.2.2 *Protection of gas insulated substations (GIS)*

GIS are, in general, better protected than open-air substations because they have surge impedances much lower than that of overhead lines. A generally valid recommendation for the estimation of the improvement obtained for GIS as compared to open-air substations cannot be made. However, the use of the formula given above for the open-air substation results in conservative estimates of the co-ordination lightning impulse withstand voltage or of the protective range and a reduction of the constant A to half the value shown in table 2 is suitable.

As a general rule, surge arresters have to be installed at the line entrance to protect the GIS, even when the line circuit breaker is open. Additional surge arresters at the transformers may be necessary, either when the separation distances to the line entrance arresters are too long, or when high overvoltages at the transformer are expected during conditions when the line entrance arresters are disconnected. Arresters installed at suitable locations inside the GIS may also be necessary for extended GIS. Improved fast-front overvoltage protection is obtained by installation of the line entrance arrester inside the GIS which eliminates the effects of the outdoor arrester leads. Although this arrester would be more expensive than an outdoor arrester, additional arresters may be superfluous and this may be the more economic solution.

When the protective ranges indicate that additional arresters should be installed within the GIS, the approximation formula should not be used, but travelling wave calculations should be performed.

Surge arrester protection for very-fast-front overvoltages within GIS is usually not possible due to the very high frequencies involved and to the delay in the conduction mechanism of metal-oxide arresters. Gapped arresters will not operate.

4.3.2.3 *Protection of cable-connected substations*

Similar to GIS, cable-connected substations are – for the same dimensions – better protected than open-air stations, but here also no generally valid recommendation can be given.

Surge arresters should be installed at the overhead line-cable terminal to protect the cable entrance. The separation distance effects can be conservatively estimated as with open-air substations. When more than one line remains connected to the substation through cables during lightning, the arresters are sufficient to protect the substation. If it is likely that cables connected to the substation are in open-end conditions during lightning, and if the cable length exceeds a value of approximately five times the value calculated with formula (12), additional arresters are recommended at the open end. This also applies to the open end of cables which are connected to the overhead line through a substation.

4.3.2.4 *Protection of cables*

Cables connected between two overhead lines should be protected by surge arresters at both terminals, if the cable length exceeds five times the value determined according to formula (12). The arrester connections to the cable terminals should follow this formula.

For cables 72,5 kV and above, the use of shield wires on the overhead line close to the cable (about three spans) and low footing impedances for the towers at the cable terminals are recommended.

Section 5: Surge arresters for special application

5.1 Surge arresters for transformer neutrals

5.1.1 *General*

One of the most widely used special applications of arresters is for the protection of transformer neutrals. Each unearthed neutral brought out through a bushing should be protected against lightning and switching overvoltages by an arrester. The neutral insulation may be overstressed in case of incoming multiphase lightning overvoltages, or in case of switching overvoltages due to asymmetrical faults in the power systems.

Furthermore, in case of resonant earthed neutral systems, high switching overvoltages may arise in the transformer neutral and across the winding when a double phase-to-earth fault is interrupted, and the circuit left connected to the transformer line side has a small capacitance to earth.

The line discharge energy absorption capability of neutral arresters should be at least the same as required for the phase-to-earth arresters or higher.

The residual voltage at a discharge current of 1 kA can be used for the determination of the protection level of the arrester, since high current values do not occur. For neutral arresters, the protection ratio may be considerably smaller due to the small rate of voltage rise.

5.1.2 *Surge arresters for fully insulated transformer neutrals*

Protection of fully insulated transformer neutrals can be achieved by using arresters having the same protection level as the phase-to-earth arresters or lower. Because of the lower power frequency voltage between neutral and earth, the rated voltage of the neutral arrester can be a lower value. A rated voltage of at least 60 % of the rated voltage necessary for the phase-to-earth arresters is recommended.

Two kinds of arresters are used:

- either the same design as for the arresters phase-to-earth, but with reduced rated voltage; or
- special arresters with reduced protection levels.

During abnormal system conditions, or during intermittent earth faults, overvoltages of long duration and amplitude high enough to cause successive arrester operation with consequent damage of the phase arresters may occur. In such cases, it is beneficial to co-ordinate the arresters so that the neutral arrester operates prior to the phase-to-earth arresters. A high energy neutral arrester may withstand the stresses and prevent damage of the phase-to-earth arresters. A switching impulse protection level of the neutral arrester of about 45 % of the switching impulse protection level necessary for the phase-to-earth arresters is recommended.

5.1.3 *Surge arresters for neutrals of transformers with non-uniform insulation*

Transformers with the dielectric strength graded from the phase terminal to the neutral are commonly applied in earthed neutral systems. If the transformer neutral is not directly earthed to limit the short-circuit currents in the system, it should be protected by an arrester with characteristics selected according to the system conditions and the withstand voltage of the neutral using the same selection methods used for the phase-to-earth arresters.

5.2 Surge arresters between phases

Considerable overvoltages between the phase terminals of transformers or reactors may occur when a reactor or a reactive loaded transformer is switched off. The withstand voltage of the reactor or the transformer between phases may be exceeded without operation of the phase-to-earth arresters. If such switching operations are expected, surge arresters should be applied between phases in addition to those applied phase-to-earth. The phase-to-phase arresters should have a continuous operating voltage equal to or higher than 1,05 times the highest system voltage. For metal-oxide surge arresters this covers temporary overvoltages up to 1,25 times the highest system voltage. For higher temporary overvoltages a value for the rated voltage has to be specified. For gapped arresters the selection of a rated voltage value is necessary to cover temporary overvoltages.

In the case of transformers with a delta-connected low-voltage winding, arresters between phases may be necessary on the low-voltage side to limit inductively transferred overvoltages. These arresters can also protect the high-voltage side of the transformer by absorbing the magnetic energy when switching off transformers.

Furnace transformers may require arresters between phases in addition to those connected phase-to-earth. For these arresters, special requirements are necessary and the arrester characteristics should be defined.

5.3 Surge arresters for rotating machines

Though a recommendation for insulation co-ordination for rotating machines has not been established, surge arresters are used to protect generators and motors against overvoltages.

Special arresters are often used for this application and the requirements have to be defined by agreement between manufacturer and user. In particular, for generator arresters attention should be paid to their pressure relief performance, since short-circuit currents may be appreciably higher than those in IEC 99-1 or IEC 99-4.

For machines which are connected to overhead lines either directly or through short cables, capacitors (0,1 to 0,3 µF) and arresters should be installed between phase and earth as close as possible to the machine terminals to extend the overvoltage front to approximately 10 µs or more, and to provide additional protection. In addition, a second set of arresters on the overhead lines in front of the machine station or at an overhead line-cable junction point may be applied.

NOTE – Besides limiting the overvoltages entering the machine station, the arresters on the overhead line cause lower discharge currents through the arresters at the machine. The resulting lower residual voltages of these machine arresters provide an additional protection of the machine.

The characteristics of the surge arresters are selected according to section 2 or section 3 and the impulse strength of the insulation or the value recommended by the manufacturer is compared with the protection level of the arrester. Generally, only small margins between protective levels and withstand voltages are achievable.

Machines connected to overhead lines through transformers may not require arrester protection in addition to the transformer protection, if the machine is connected by sufficiently long cables, or if capacitors of the values mentioned above are installed. If a breaker is installed between the transformer and the rotating machine, the capacitors should be installed at the transformer terminals (generator winding).

For machines connected to star-delta transformers, improved protection can be achieved by additional phase-to-phase arresters. Arresters installed at the machine or at the machine side of the transformer are not subjected to high lightning currents. Therefore, low protection levels can be achieved with low sparkover voltages (in case of gapped arresters) and low residual voltages at discharge currents of 500 A or less.

Large turbogenerators have low surge impedances and single-phase enclosed busbars and short circuits between phases must be avoided. Surge arresters should not be installed phase-to-phase. Sufficient protection may be achieved by the arresters at the transformer high-voltage side.

5.4 Further special applications of surge arresters

Selection and installation of surge arresters for protection of the following apparatus are to be adapted to the special requirements of the equipment as determined between user and manufacturer of the apparatus to be protected:

- Cable sheaths should be earthed at both terminals. If this is not possible for single-phase cables due to the reduction of the cable load capability, the unearthed cable sheath end should be protected by surge arresters. The rated voltage of these arresters should be higher than the induced sheath-to-earth voltage at maximum fault current. This covers the required continuous operating voltage. The nominal discharge current should be the same as that of the phase-to-earth arresters at the cable terminals. The protection level should be as low as possible, because the withstand strength of the sheath during its service life is not well defined and is not assured by any standardized test;
- special transformers, e.g. series windings of autotransformers and converter transformers;
- series reactors, e.g. current limiting reactors, high frequency reactors and series capacitors;
- resonant circuits;
- a.c. traction systems;
- overhead lines.

5.5 Surge arresters for abnormal service conditions

For abnormal service conditions mentioned in annex A of IEC 99-1 or in annex A of IEC 99-4, special considerations in the design or in the application of surge arresters are needed and should be called to the attention of the manufacturer.

Examples for such conditions are:

- altitudes above 1 000 m;
- temperatures outside the range –40 °C to 40 °C;
- live washing of surge arresters;
- high wind forces;
- earthquakes;
- limitation of clearances to conducting surfaces.

Section 6: Monitoring (supervision)

6.1 General

Different systems are used to monitor surge arrester operation or possible deterioration in systems of 72,5 kV and above. If surge counters or monitoring spark gaps are installed, the arrester base and the conductor between the arrester and this monitoring instrument should be insulated against earth due to the voltage drop across the monitoring instrument and along the connection lead, especially when the instrument is not installed adjacent to the arrester. The connection lead should not considerably lengthen the earth connection of the arrester and its cross-section should not be less than that for usual earthing connections.

In systems lower than 72,5 kV, examination of some arresters in service is used to verify arrester conditions.

6.2 Discharge counters

Discharge counters should be installed so that they can be read from ground level. Discharge counters usually operate at impulse currents above a certain amplitude and duration. Some counters require power follow current and may, therefore, not count short discharge currents through metal-oxide arresters. If the interval between discharges is very short (below 50 ms), discharge counters may not count every operation. Discharge counters have the advantage that they can be read with the arrester energized. Discharge counters generally give no information on the current amplitudes.

6.3 Monitoring spark gaps

The monitoring spark gaps provide some indication of the number of operations, the amplitude and the duration of the discharge current. They can only be examined when the arrester is de-energized. Special experience is necessary to properly interpret the marks on the gap. Monitoring spark gaps are usually checked when there is reason to believe that arrester operations have occurred.

6.4 Device for monitoring the continuous current

The current through the arrester at operating voltage can be measured by a properly connected instrument. Care must be taken that the measured value is not superposed by a current on the porcelain surface caused by pollution. Therefore, readings should be taken only when the surface is dry or the surface current is diverted by special measures.

When the current through metal-oxide arresters at operating voltage is measured to obtain information about possible varistor degradation, the resistive component of the current should be isolated to achieve sufficient sensitivity. Voltage reference is needed to measure this resistive component or the corresponding power losses with sufficient accuracy. Furthermore, the ambient temperature during the measurement should be observed and recorded.

NOTE – The measurement of the total current through the arrester is less expensive but less sensitive and often not meaningful.

Annex A
(informative)

Determination of temporary overvoltages due to earth faults

The earth fault factor k is the ratio of the highest r.m.s. phase-to-earth power frequency voltage on a sound phase at a particular location during a fault to earth (affecting one or more phases at any point) to the r.m.s. phase-to-earth power frequency voltage which should be obtained without the fault (see 3.17 of IEC 71-1).

The earth fault factor is calculated using the complex impedances Z_1, Z_2 and Z_0 of the positive, negative and zero sequence systems, taking into account the fault resistance R. The following applies:

$Z_1 = Z_2 = R_1 + jX_1$: resistance and reactance of positive and negative sequence system;

$Z_0 = R_0 + jX_0$: resistance and reactance of zero sequence system.

The earth fault factors are calculated for the location of the fault.

NOTE – It should be observed that in extended resonant earthed networks the earth fault factor may be higher at other locations than the fault.

Figure A.1 shows the overall situation, when $R_1 << X_1$ and $R = 0$.

The range of high values for X_0/X_1, positive and/or negative, apply to resonant earthed or isolated neutral systems.

The range of low values of positive X_0/X_1 are valid for earthed neutral systems.

The range of low values of negative X_0/X_1, shown hatched, is not suitable for practical application due to resonant conditions.

For earthed neutral systems, figures A.2 through A.5 show the earth fault factors as families of curves applicable to particular values of R_1/X_1.

The curves are valid for fault resistance values giving the highest earth fault factors.

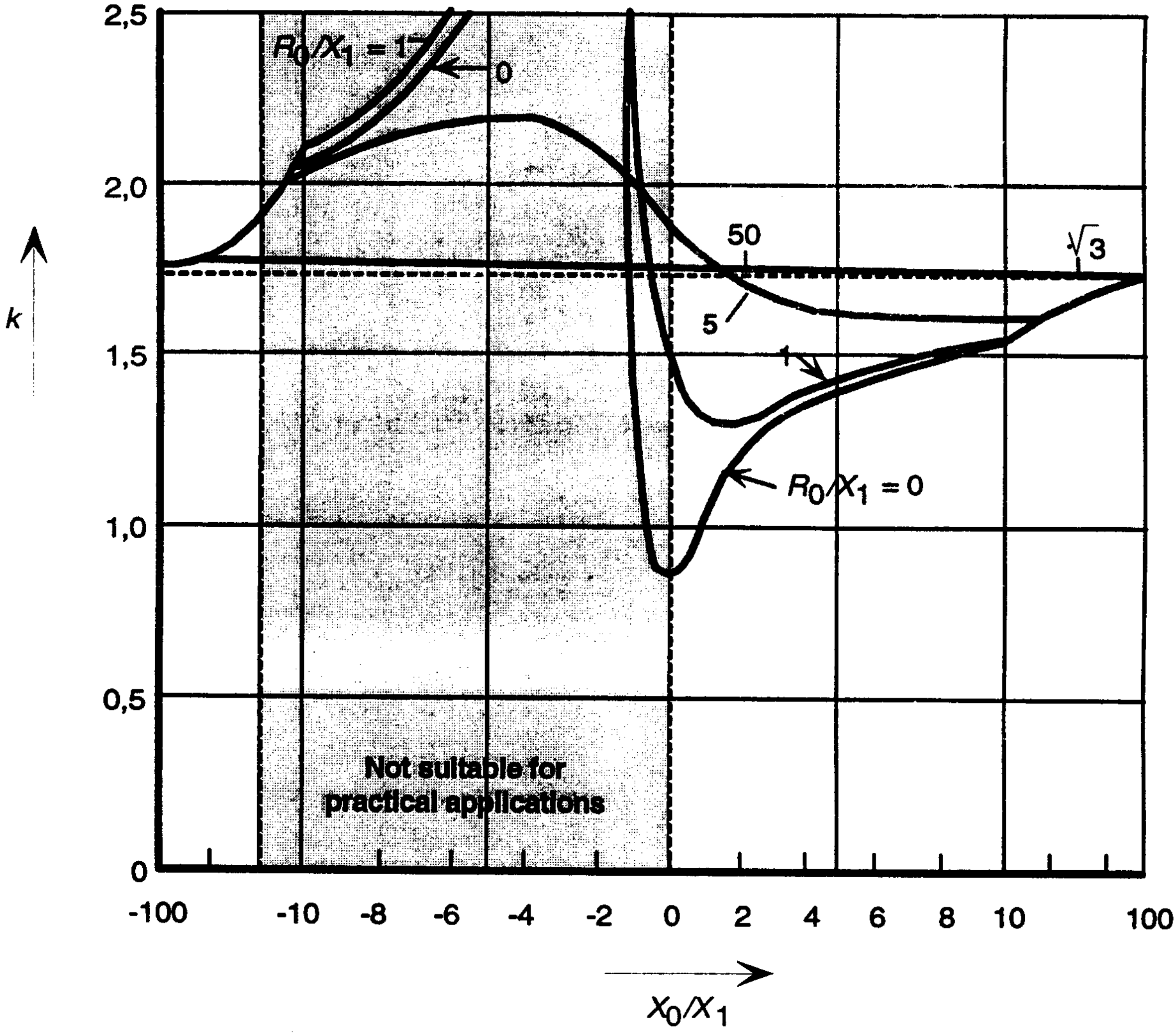
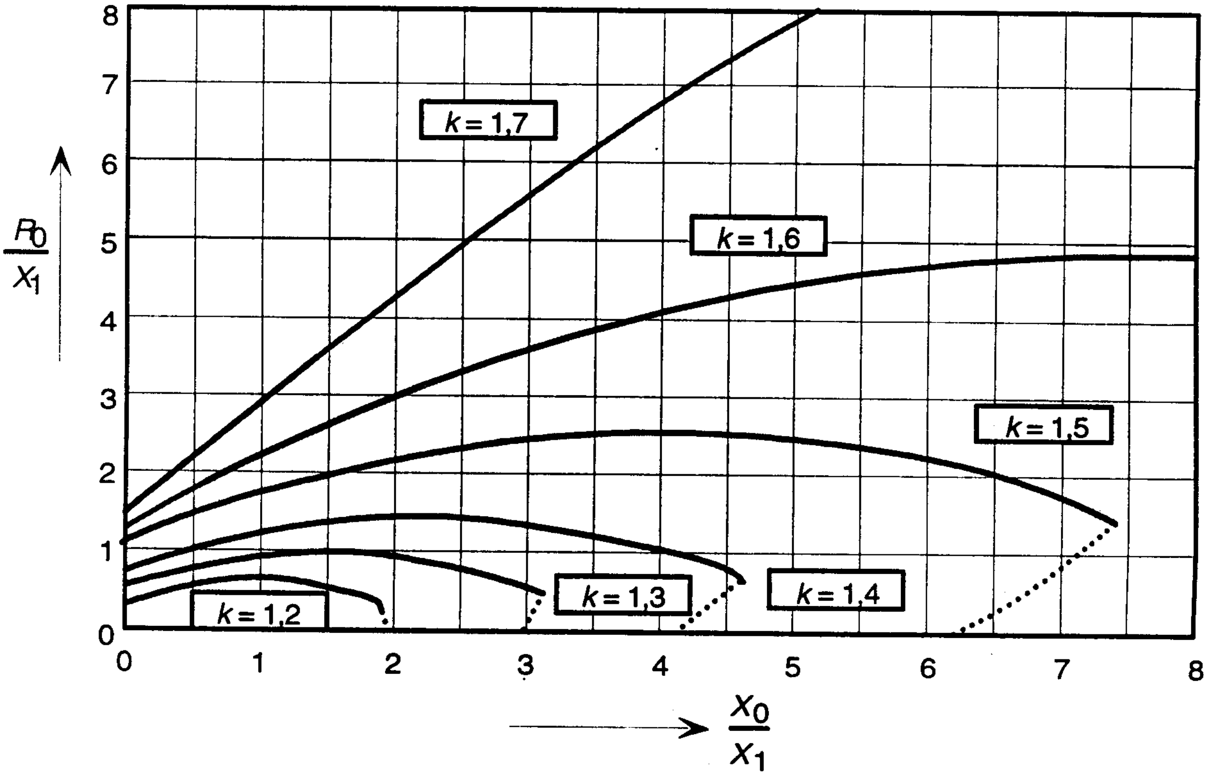


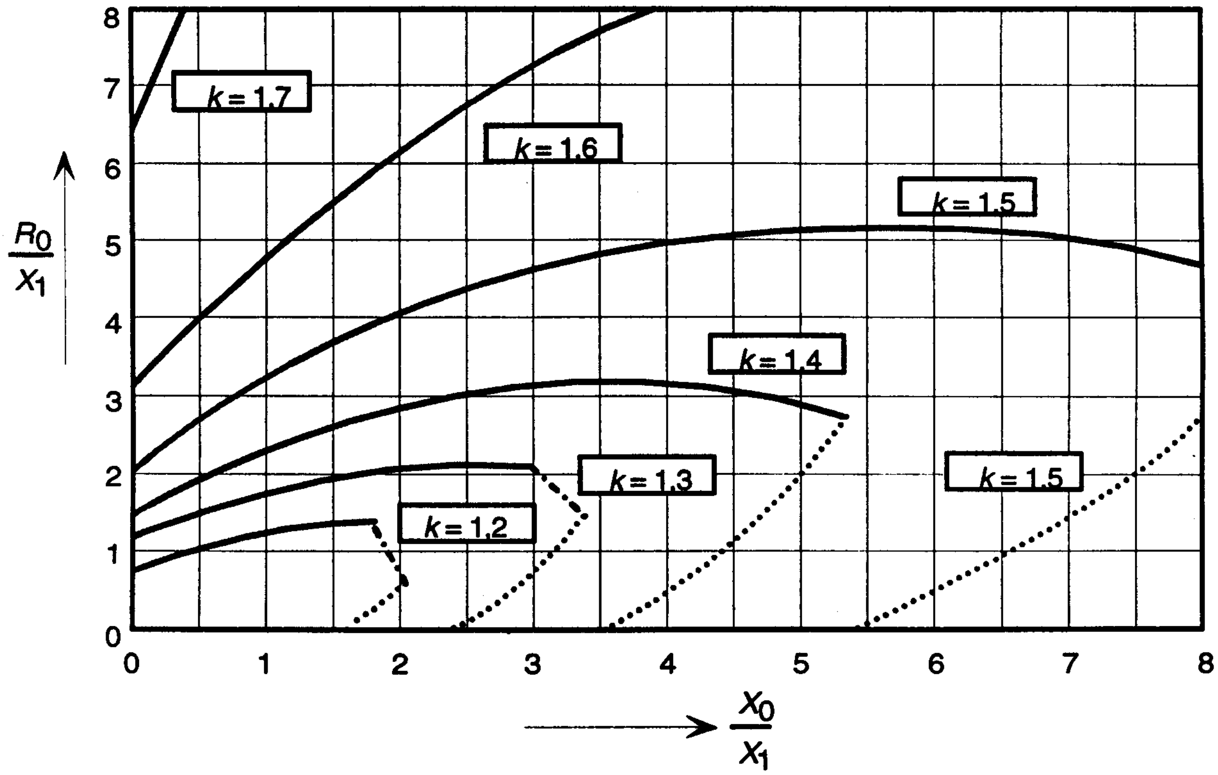
Figure A.1 – Earth fault factor k on a base of X_0/X_1, for $R_1/X_1 = R = 0$



The curves are divided into regions representing the most critical conditions by the following methods of presentation:

————————————	maximum voltage occurs during a phase-to-earth fault on the phase which leads the faulted phase;
....	maximum voltage occurs during a phase-to-earth fault on the phase which lags the faulted phase;
.–.–.–.–.–.–.–.–.–	maximum voltage occurs during a phase-to-earth fault on the unfaulted phases.

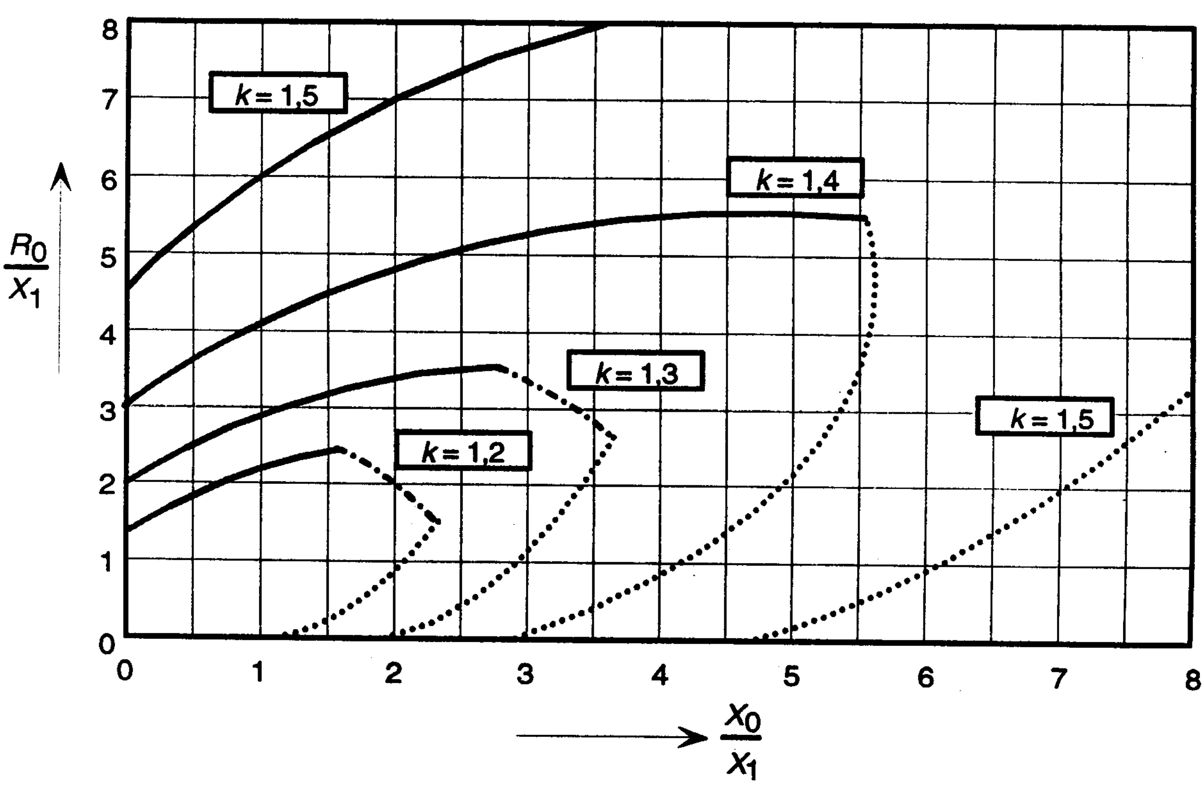
Figure A.2 – Relationship between R_0/X_1 and X_0/X_1 for constant values of earth fault factor k where $R_1 = 0$



The curves are divided into regions representing the most critical conditions by the following methods of presentation:

————————————	maximum voltage occurs during a phase-to-earth fault on the phase which leads the faulted phase;
··························	maximum voltage occurs during a phase-to-earth fault on the phase which lags the faulted phase;
·–·–·–·–·–·–·–·–·–	maximum voltage occurs during a phase-to-earth fault on the unfaulted phases.

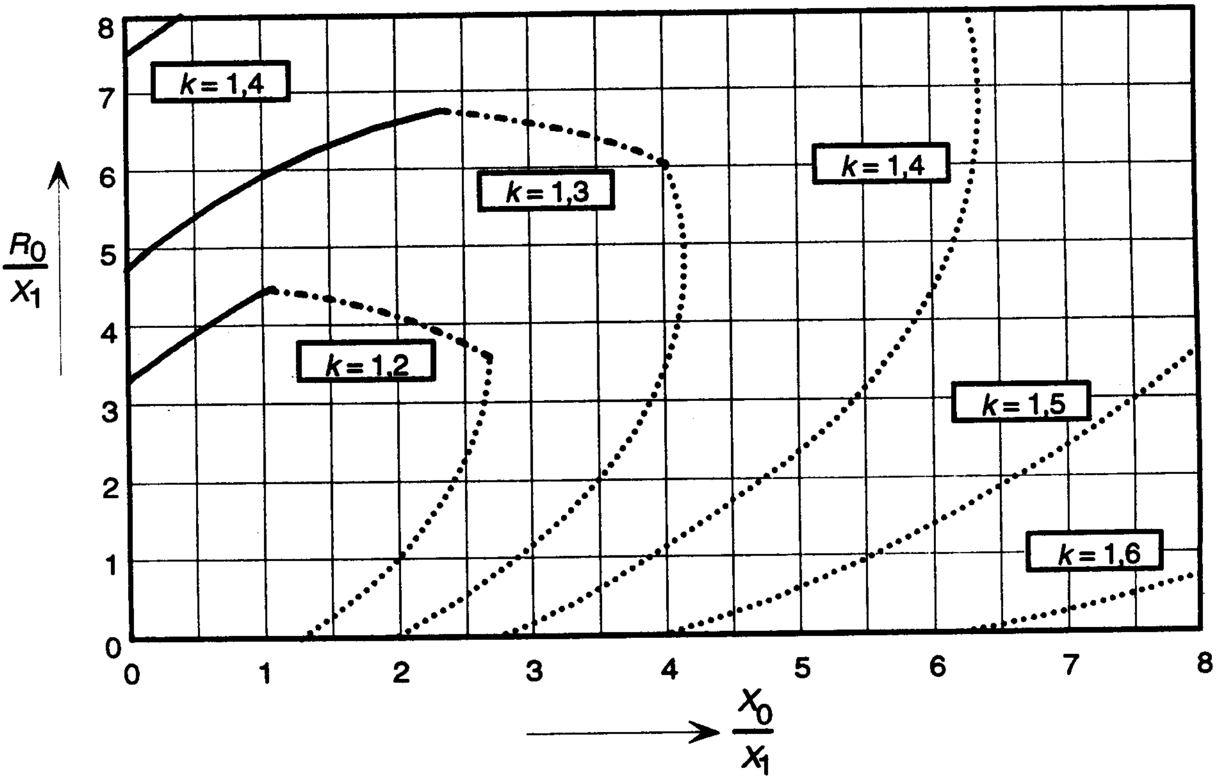
Figure A.3 – Relationship between R_0/X_1 and X_0/X_1 for constant values of earth fault factor k where $R_1 = 0,5\ X_1$



The curves are divided into regions representing the most critical conditions by the following methods of presentation:

________________________	maximum voltage occurs during a phase-to-earth fault on the phase which leads the faulted phase;
....	maximum voltage occurs during a phase-to-earth fault on the phase which lags the faulted phase;
._._._._._._._._._._._.	maximum voltage occurs during a phase-to-earth fault on the unfaulted phases.

Figure A.4 – Relationship between R_0/X_1 and X_0/X_1 for constant values of earth fault factor k where $R_1 = X_1$



The curves are divided into regions representing the most critical conditions by the following methods of presentation:

————————	maximum voltage occurs during a phase-to-earth fault on the phase which leads the faulted phase;
··························	maximum voltage occurs during a phase-to-earth fault on the phase which lags the faulted phase;
·–·–·–·–·–·–·–·–·–	maximum voltage occurs during a phase-to-earth fault on the unfaulted phases.

Figure A.5 – Relationship between R_0/X_1 and X_0/X_1 for constant values of earth fault factor k where $R_1 = 2X_1$

Annex B
(informative)

Current practice

For the power supply systems within some countries the application of this standard may result in tables of consistently used surge arrester characteristics. For the use of this standard within such countries, tables containing these characteristics may be added to this annex B, without deviating from the standard.

Annex C
(informative)

Bibliography

[1] *J. Elovaara, K. Foremann, A. Schei, O. Völcker:* "Metal-oxide surge arresters in a.c. systems. Part 3: Temporary overvoltages and their stresses on metal-oxide surge arresters".
ELECTRA 128 (1989) 114 ... 125

[2] *A.R. Hileman, J. Roguin, K.-H. Weck:* "Metal-oxide surge arresters in a.c. systems. Part 5: Protection performance of metal-oxide surge arresters".
ELECTRA 133 (1990) 132 ... 144

[3] *L. Stenström:* "Metal-oxide surge arresters in a.c. systems. Part 6: Selection of metal-oxide surge arresters from the standards".
ELECTRA 133 (1990) 146 ... 165

[4] *A. Schei, A. Ekström:* "Stresses on metal-oxide surge arresters in HVAC and HVDC systems by temporary and transient overvoltages and related tests".
CIGRE 1986, Rapport 33-13

(*Continued from second cover*)

International Standard	*Corresponding Indian Standard*	*Degree of Equivalence*
60507 : 1991 Artificial pollution tests on high voltage insulators to be used on ac systems	IS 8704 : 1995 Artificial pollution on high voltage insulators to be used on a.c. systems (*first revision*)	Equivalent
60815 : 1986 Guide for the selection of insulators in respect of polluted conditions	IS 13134 : 1992 Guide for selection of insulators in respect of pollution conditions	do

For the purpose of deciding whether a particular requirement of this standard is complied with, the final value, observed or calculated, expressing the result of a test, shall be rounded off in accordance with IS 2 : 1960 'Rules for rounding of numerical values (*revised*)'. The number of significant places retained in the rounding off value should be the same as that of the specified value in this standard.

Only the English text of the International Standard has been retained while adopting it in this Indian Standard.

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